REMARKS

This amendment is being filed in response to the Office Action from the Examiner dated March 28, 2003. A three month extension of time to respond is also enclosed. The comments of the Examiner in his objection to the drawings and specification, and his rejection of claims 1-16 based on 35 USC 112 (first and second paragraphs), 102(b) and 103(a) have been given consideration by the Applicant and, in view of those comments, Applicant submits the foregoing amendments as placing the claims in condition for allowance and requests favorable consideration of the amended claims.

Turning first to the drawings, page 6 of the specification indicates that Fig. 3 shows a detail view of one end of the view of Fig. 2. As such, the hatched portion of Fig. 2 indicated as comprising the subject matter of Fig. 3 may in fact be appreciated from the specification as being the subject matter which is disclosed on an enlarged scale in Fig. 3. Thus, Applicant submits that there is no reason to do any relabeling.

With respect to reference numeral 46, the specification has been amended in paragraph [0024] to include mention of this reference numeral which was accidentally omitted. Its addition does not constitute the introduction of new matter.

With respect to Fig. 5, a corrected copy of the drawing page is attached having in its top margin the words "Replacement Sheet" showing the inner tube member 12 as being made from metal, however it should be noted that the specification does not state that it has to be made from metal, merely that metal is the preferable substance from which the inner tube is fabricated. The correction is being made to avoid confusing the

reader, inasmuch as the Examiner felt it should be clearly shown as being of metal. It should also be appreciated that due to the narrowness associated with this portion of the drawing figure, attempts to make the diagonal lines appear that way can end up with lines that appear substantially vertical or with mere dots seeming to exist between the lines.

With respect to the "adhesion layer" described on page 8 of the specification as filed, Applicant submits that this is shown by reference numeral 48 in Fig. 5.

With respect to the fibers "being oriented at a single angle" which the Examiner states as being incorrect because he construes there as being two angles α and –α citing to Fig. 2a of U.S. Pat. No. 3,850,722, Applicant submits that upon reconsideration by the Examiner, Fig. 4A is correct. While the Examiner refers to Fig 2a, Applicant submits that Fig. 2b is actually more on point. Applicant calls the attention of the Examiner to Fig. 2b of the '722 patent and the discussion in that patent of "α" found at col. 4, lines 33-54. The wording in the cited patent with respect to what is the angle defined as "α" is submitted as being similar to the language utilized by Applicant in paragraphs [0030, 0033, 004142, 0044], with particular attention being called to the language in paragraph [0030] where "α" is defined by Applicant as being "relative to the longitudinal axis 42". This language of Applicant corresponds strongly to the language in the '722 patent at col. 4, lines 35-37 where "α" is defined as being "with respect to the longitudinal center line of the component". Thus this objection should be withdrawn.

With respect to the drawings showing a "geodesic isotensoid elliptical shape", Applicant submits that they do. Pertinent pages from <u>Handbook of Composites</u> are submitted that discuss the wrapping that occurs in pressure vessels and particularly the

geodesic isotensoid shape associated with the wrapping that occurs at the end of the pressure vessel. In Applicant's invention, since a longitudinal axis extends the length of the claimed invention with its symmetrical ends, the wrapped shape that is generated must be a geodesic isotensoid elliptical shape, such that it in fact is what is shown.

Turning now to the objections to the specification, the definition of the acronym, "CNC" well known to those of ordinary skill in the art of the manufacture of pressure vessels has been incorporated into the specification, such that this objection has been overcome.

With respect to proper antecedent basis for "elongated fibers which are oriented relative to the curvature of the portion of the end piece", Applicant calls the attention of the Examiner to paragraphs [0044 and 0045] which discuss the fact that the fibers are applied in a way which extends from one end of the tube to the other, i.e. they are elongated, and that their wrapping is done in a geodesic isotensoid elliptical shape (see Handbook of Composites) such that when the composite material has cured the fibers transfer shear loads efficiently through the composite material. This limitation is what is set forth in claim 7, such that Applicant submits that there is antecedent basis for the language found in the claim.

With respect to claim 9 and the word "mandrel", Applicant refers the Examiner to paragraph [0009] which states that the inner tube of the invention acts as a mandrel. Applicant also refers the Examiner to the attached portion of Handbook of Composites, where at the bottom of page 458 the word "mandrel" is repeatedly used. One of ordinary skill in the art knows that a "mandrel" is nothing more than a mold over which something

can be molded, in Applicant's case the wrapped fibers which ultimately surround the inner tube. Thus, Applicant submits there is antecedent basis for the language found in the claim.

With respect to claim 13 having language about "an elongated" inner tube member, Applicant refers the Examiner to paragraph [0026], where the shaft formed with the inner tube member extends from end-to-end and has a longitudinal axis 42. Thus, Applicant submits there is antecedent basis for the language found in the claim.

Turning now to the rejections under Section 112, first paragraph, claims 3, 6, 8, and 13-16 were rejected. With respect to the rejections concerning claims 3 and 14, they have been satisfied by the amending of claim 3 and 14 to incorporate language similar to that found in paragraph [0032].

With respect to the rejections concerning claims 6 and 16, those claims have been amended to clarify the connections associated with the multiple load paths discussed in paragraph [0024]. The limitations in both claims concern the multiple load paths.

With respect to the rejections concerning claims 8 and 13, Applicant calls the attention of the Examiner to the attached pages from the Handbook of Composites which make it clear that the equations referenced by Applicant in its specification would be well known to one of ordinary skill in the art. In point of fact, Applicant uses a commercially available program put out by NASA in the making of the object as claimed. Thus, undue experimentation would not be required.

Claims 3, 8, and 12-16 were rejected under 35 USC 112, second paragraph. The Examiner's comments concerning claims 3 and 14 have to do with the angle "α", which

Applicant has discussed above in connection with the Examiner's objection to the drawings. The comments of Applicant above are equally applicable here, and consequently, one of ordinary skill in the art would appreciate that all of the fibers in Applicant's invention are oriented at a single angle, as the '722 makes clear. Therefore, this ground of rejection should be withdrawn.

The Examiner's comments concerning claims 8 and 13 concerning the terminology "geodesic isotensoid elliptical shape" have also been addressed by Applicant above, and as such this ground of rejection should be withdrawn. Finally, with respect to the rejection of claim 12 under Section 112, second paragraph, claim 12 has been amended to definitely define the sacrificial layer 52 as being thinner than the layer of composite material 18 which limitation can easily be appreciated from the drawings.

Turning now to the rejections under 35 U.S.C. 102(b), claims 1, 4-7, and 9-12 have been rejected as being anticipated by Williams '978. Applicant submits that a thorough reading of Williams '978 discloses that its shaft is fabricated from foam, which anyone of ordinary skill in the art would readily appreciate as being unable to carry a load. While Williams' foam acts as a mandrel, it fails to address the carrying of torsional loads as claimed by Applicant. Since the device disclosed in the Williams reference could not carry loads as claimed by Applicant, the reference does not anticipate the invention of Applicant. Thus, this ground of rejection must be withdrawn.

Turning now to the Section 102 rejection of claims 1, 4-7, and 9-12 based on Williams '884, Applicant submits that a thorough reading of Williams '884 discloses that its shaft is fabricated from foam, which anyone of ordinary skill in the art would readily

appreciate as being unable to carry a load. While Williams' foam acts as a mandrel, it fails to address the carrying of torsional loads as claimed by Applicant. Since the device disclosed in the Williams reference could not carry loads as claimed by Applicant, the reference does not anticipate the invention of Applicant. Thus, this ground of rejection must be withdrawn.

Turning now to the Section 102 rejection of claims 1, 2, 4-7, and 9-12 based on Kreft, Applicant notes that Kreft discloses a shape imparting core 5 made of an aerated plastic. It is a solid device, not one with opposing open ends as now claimed by Applicant. Thus, this ground of rejection must be withdrawn.

Turning now to the Section 102 rejection of claims 1, 4, 9-10 based on Underwood, Applicant takes issue with the Examiner calling the invention of Underwood a "shaft", since Underwood goes to great pains to discuss his invention as being that of a "container" i.e. a pressure vessel. Since the reference concerns a pressure vessel, Underwood never discusses the transmission of torsional loads. Applicant submits that one of ordinary skill in the art would readily appreciate the fact that a pressure vessel is significantly different from a drive shaft. As such, Underwood does not disclose a drive shaft capable of transmission of torsional loads as claimed by Applicant. Thus, this ground of rejection must be withdrawn.

Turning now to the Section 102 rejection of claims 1, 4, and 9-11 based on Palmer, the reference discloses an assembly of a composite shaft and a yoke member of a Hookes universal joint. Assuming the yoke member corresponds to Applicant's "end piece", all portions of the Palmer device covered by the composite material are either flat

or concave, while Applicant specifically recites that the portion of the end piece covered by the composite material defines a convexly curved area of the end piece. Consequently, Palmer does not disclose the invention as claimed. Thus, this ground of rejection must be withdrawn.

Turning now to the Section 103 rejection of claim 3 based on Kreft in view of the SAE publication, Applicant has noted above that Kreft discloses a shape imparting core 5 made of an aerated plastic. It is a solid device, not one with opposing open ends as now claimed by Applicant. While the SAE publication discusses universal joint and driveshaft design, given the longfelt need in the art, that need has remained unaddressed until Applicant's invention. Therefore, it is submitted that the invention as now claimed is not obvious. Thus, the ground of rejection should be withdrawn.

Turning now to the Section 103 rejection of claims 8, 13, 15-16 based on Williams '978 in view of Hannibal et al, Applicant submits that there is no reason to make the combination suggested by the Examiner. Hannibal teaches the solution for transmitting torque and accommodating axial and angular misalignment due to drive shafts is to fabricate a coupling member that has its opposite sides connected to drive shafts, with the coupling member wrapped following a geodesic path. Thus, one of ordinary skill in the art having the two references in front of them would at most find it obvious to use the shaft precisely as disclosed in Williams but with the wrapped couplings as taught by Hannibal at each end of the shaft. Based on the teachings of Hannibal, there would be no need to have the shaft wrapped, and there is no suggestion or motivation in Williams to require that it be wrapped in a geodesic manner. Thus, the

suggested combination would not be obvious, since to follow the teachings of both references would not result in the device as claimed by Applicant. Thus, the ground of rejection should be withdrawn.

Turning now to the Section 103 rejection of claims 8, 13, 15-16 based on Williams '884 or Kreft in view of Hannibal, Applicant submits that there is no reason to make the combination suggested by the Examiner. As stated above, Hannibal teaches the solution for transmitting torque and accommodating axial and angular misalignment due to drive shafts is to fabricate a coupling member that has its opposite sides connected to drive shafts, with the coupling member wrapped following a geodesic path. Thus, one of ordinary skill in the art having either the Williams '884 or Kreft references in front of them would at most find it obvious to use the shaft precisely as disclosed in Williams or the pressure vessel as disclosed in Kreft but with the wrapped couplings as taught by Hannibal at each end of those devices. Based on the teachings of Hannibal, there would be no need to have the object between the couplings wrapped, and there is no suggestion or motivation in Williams to require that its shaft be wrapped in a geodesic manner, or to require that the pressure vessel of Kreft be so wrapped. Thus, either of the suggested combinations would not be obvious, since to follow the teachings of the references cited by the Examiner would not result in the device as claimed by Applicant. Thus, the ground of rejection should be withdrawn.

Turning now to the rejection under Section 103 of claim 14 based on Kreft in view of Hannibal and further in view of the SAE publication, Applicant has noted above that Kreft discloses a shape imparting core 5 made of an aerated plastic. It is a solid

device, not one with opposing open ends as now claimed by Applicant. While the SAE publication discusses universal joint and driveshaft design, given the longfelt need in the art, that need has remained unaddressed until Applicant's invention. Therefore, it is submitted that the invention as now claimed is not obvious. Thus, the ground of rejection should be withdrawn.

With respect to the other items of prior art cited by the Examiner, yet not relied upon, Applicant submits that none of these references either alone or in combination with the others cited by the Examiner, anticipate or render obvious the invention as now claimed by Applicant.

In view of the amendments to the drawings, specification and claims, and the foregoing remarks, claims 1-16 are submitted for further consideration as being patentable. The allowance of these claims is respectfully solicited. If the Examiner has any questions which would expedite issuance of a Notice of Allowance, a telephone call to the undersigned is requested. The Commissioner is authorized to charge Deposit Account No. 13-3393 for any insufficient fees under 37 CFR §§ 1.16 or 1.17, or credit any overpayment of fees.

Respectfully submitted,

Kremblas, Foster, Phillips & Pollick

By [signature]
Patrick P. Phillips / Registration No. 29,690

7632 Slate Ridge Blvd.
Reynoldsburg, Ohio 43068
(614) 575-2100 / (614) 575-2149 FAX
pphillips@ohiopatent.com
September 29, 2003
Enclosures — Note: New Power of Attorney!

HANDBOOK OF COMPOSITES

Edited by

George Lubin

CONSULTANT

Formerly—Chief Scientist
Grumman Aerospace Corporation

Sponsored by the Society of Plastics Engineers

VAN NOSTRAND REINHOLD COMPANY

To BEATRICE
CARYN
GLENDA
SHIRLEY
TERRI

Library of Congress Catalog Card Number: 81-10341
ISBN: 0-442-24897-0

Manufactured in the United States of America

Published by Van Nostrand Reinhold Company Inc.
135 West 50th Street
New York, New York 10020

Van Nostrand Reinhold Company Limited
Molly Millars Lane
Wokingham, Berkshire RG11 2PY, England

Van Nostrand Reinhold
480 Latrobe Street
Melbourne, Victoria 3000, Australia

Macmillan of Canada
Division of Gage Publishing Limited
164 Commander Boulevard
Agincourt, Ontario M1S 3C7, Canada

15 14 13 12 11 10 9 8 7 6 5 4 3 2

Library of Congress Cataloging in Publication Data

Main entry under title:

Handbook of composites.

(A Society of Plastics Engineers technical monograph)
A follow on text to Handbook of fiberglass and advanced plastics composites. 1969.
Includes index.
1. Composite materials—Handbooks, manuals, etc.
2. Fibrous composites—Handbooks, manuals, etc.
I. Lubin, George. II. Handbook of fiberglass and advanced plastics composites. III. Series: Society of Plastics Engineers technical monograph.
TA418.9.C6H33 1981 620.1'18 81-10341
ISBN 0-442-24897-0

Table 16.7. Properties of Polyester and Vinyl Ester Resins

Resin	Derakane 411	Derakane 510-A	Epocryl 480	Epoxy Novolac	6100-10
Manufacturer	Dow	Dow	Shell		Koppers
Type	VE	VE	VE	VE	Iso-PE
Tensile					
Ultimate, ksi (MPa)	11.5 (79)	10.5 (72)	12.2 (84)	11.3 (78)	8.0 (55)
Modulus, psi × 10^5 (GPa)	4.9 (3.4)	5.0 (3.4)	4.7 (3.2)	4.7 (3.2)	
Elongation, %	4.7	6.5	5.3	5.3	12–15
Flexural,					
Ultimate, ksi (MPa)	17.0 (117)	17.0 (117)	17.0 (117)	16.3 (105)	13.8 (94)
Modulus, psi × 10^5 (GPa)	4.5 (3.1)	5.2 (3.6)	4.7 (3.2)	4.6 (3.2)	3.9 (2.7)
Heat deflection temperature, °F (°C)	220 (104)	230 (110)	250 (121)	250 (121)	

elongation of 3–7% is a desirable property. Cure shrinkages are estimated to be in the order of 7–10%. Shrinkage increases at higher styrene contents.

16.3. THE WINDING PROCESS

16.3.1. Winding Methods and Patterns

The two basic processes are identified as polar and helical winding. Each method produces a distinctive filament pattern. In polar (also called planar) winding, the mandrel remains stationary while a fiber feed arm rotates about the longitudinal axis, inclined at the prescribed angle of wind. The mandrel is indexed to advance one fiber bandwidth for each rotation of the feed arm. This pattern is described as a single circuit polar wrap (Fig. 16.3). The fiber bands lie adjacent to each other; a completed layer consists of two plies oriented at plus and minus the winding angle.

In the helical mode, the mandrel rotates continuously while the fiber feed carriage traverses back and forth. The carriage speed and mandrel rotation are regulated to generate the desired winding angle. The normal pattern is multi-circuit helical. After the first traverse, the fiber bands are not adjacent. Several circuits are required before the pattern repeats. (A typical ten-circuit pattern is represented in Fig. 16.4.) The filament path advances one-tenth of the circumference plus one-tenth of the bandwidth per circuit; the eleventh path then falls alongside the first. A layer again contains two plies. This configuration characteristically results in fiber intersections (fiber crossovers) at certain sections. Crossovers may occur at more than one section, depending on the wind angle.

Winding patterns are determined by trial and error machine adjustments or are calculated from the geometry. The following simplified example illustrates a method of establishing the circuits per pattern and the total number of circuits for complete coverage of the mandrel.

Example: To wind a 10 in. (25.4 cm) diameter by 40 in (101.6 cm) long cylinder at a 45°

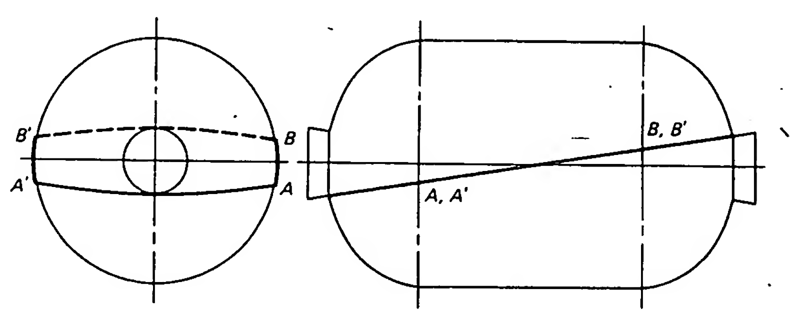


Figure 16.3. Single circuit planar path.

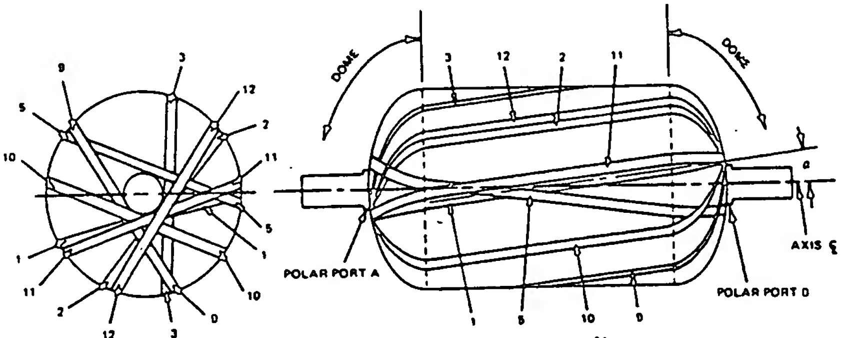


Figure 16.4. Ten-circuit helical pattern.[24]

wrap angle. The fiber bandwidth is assumed to be 0.250 in. (0.64 cm) and the dwell angle 180°. (The dwell angle is a measure of mandrel rotation at each end before the travel direction of the feed is reversed.)

In one circuit, the feed moves 80 in. (203.2 cm), while the mandrel rotates $80/10\pi$ revolutions plus one revolution of dwell, or a total of 1276.8°. The fiber path is thus advanced 196.8° (1276.8° − 3 × 360°). This angle will not give a closed pattern. The simplest adjustment is to increase the dwell at each end by 1.6°, so that the advance will be 200°. At this angle, the fiber paths will coincide after nine circuits. The total number of circuits per layer is:

$$C_L = \pi D / S_C$$

where D is the mean composite diameter, S_C is the circumferential component of bandwidth, and $S_C = 0.354$ for a 45° wind.

$$C_L = 10\pi / 0.354 = 88.8.$$

The bandwidth is reduced slightly so that C_L is equal to 90, which allows for ten repeating patterns. The ratio of mandrel speed to traverse speed is finally adjusted so that the fiber path advances an additional 0.354 in. (0.9 cm) in the nine circuits.

The degree of precision in controlling machine speeds is apparent from the example. It is seen that bandwidth and dwell angle are varied to obtain complete coverage. In practice, the cylindrical length and wind angle are also considered as variable in realizing a satisfactory pattern.

Other winding types include the following.

Hoop Winding. Hoop or circumferential layers are wound close to 90°; the feed advances one bandwidth per revolution. The layer is considered to be a single ply. (Hoop layers may also be applied as doublers or localized stiffeners at strategic points along the cylinder.)

Longitudinal Winding. This term applies to low angle wraps which are either planar or helical. For closed pressure vessels, the minimum angle is determined by the polar openings at each end.

Combination Winding. Longitudinals are reinforced with hoop layers; the customary practice with pressure vessels is to place the bulk of the hoop wraps in the outer layer. A balance of hoop and longitudinal reinforcement can also be achieved by winding at two or more helical angles.

Miscellaneous. Included here are multi-circuit planar wraps analogous to multi-circuit helicals, a single circuit helical wrap similar to a planar wind. Both patterns differ from their counterparts only in regard to the fiber path over the end closures.

16.3.2. Winding Machines

These machines are designed for either polar or helical winding. Variations are made in each type to accommodate hoop windings and to add versatility. Polar winders usually operate with the mandrel in a vertical position which eliminates deflections due to weight and permits a simpler construction of the rotating feed arm. A major advantage of the polar machine is that simpler control of the machine motions is possible. The rotation of the feed arm is continuous and at a uniform speed, so that there are no inertial effects which can occur when speeds are varied or

directions reversed. On the other hand, operation is limited to prepreg feedstock in most cases, since a wet winding system is difficult to install.

The basic movements of the helical winder are mandrel rotation and feed traverse. To these can be added a cross-slide perpendicular to the mandrel axis and a fourth axis of motion, rotation of the feed eye. These latter two permit more accurate fiber placement over the ends. Controls may be either mechanical or numerical. Mechanical control usually implies a single drive system in which rotation and traverse are fixed by gear trains, link chains, or drive screws. The motions of the numerical winder are controlled by punched tape operation of hydraulic servo drives, each axis having its own hydraulic motor. A recent innovation by one manufacturer utilizes a microcomputer to control servo motors. A silicon chip performs the logic, memory, and calculations for machine function.

Other machines are designed for specific structures. Figure 16.5 is a schematic representation of a spherical winder.[10] A 12-bit minicomputer furnishes control of the machine, which can wind spheres 3–15 in. (7.6–38 cm) in diameter.

Companies which manufacture filament winding machines and auxiliary equipment are listed below:

Brenner. I. G. Co., Newark, Ohio
Engineering Technology, Inc., Salt Lake City, Utah.
Gavlick Machinery Corp., Bristol, Connecticut.

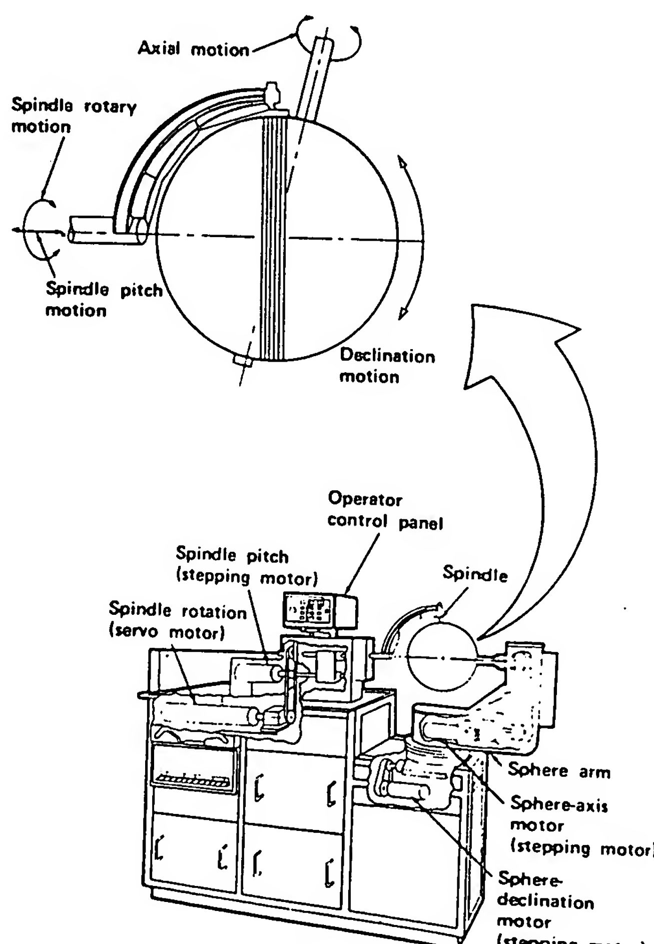


Figure 16.5. Lawrence Livermore Laboratory spherical winder.[10]

Goldsworty Engineering, Inc., Torrance, California.
McClean-Anderson, Inc., Milwaukee, Wisconsin.
Thaden Engineering Co., High Point, North Carolina.
Venus Products, Inc., Kent, Washington.
Vermont Instrument Co., Inc., Burlington, Vermont.

16.3.3. Mandrels

Mandrel design is comparatively simple for open end structures such as cylinders or conical shapes. Either cored or solid steel or aluminum serves satisfactorily. When end closures are integrally wound, as in pressure vessels, careful consideration must be given to mandrel design and selection of a suitable material. A proper design will minimize fiber damage during part removal as well as dimensional intolerances and excessive residual stresses. The mandrel must resist sagging due to its weight and applied winding tension. It must retain sufficient strength during cure at elevated temperatures and be easy to remove after cure. Construction concepts include the following.

1. *Segmented collapsible metal.* These are costly and are not warranted for less than 25 parts. The suggested diameter range is 3–5 feet (0.91–1.52 m). Removal can be complicated with small polar openings.

2. *Low melting alloys.* These are high in density and tend to creep under moderate winding tension. They are limited to small vessels in the order of 1 ft (0.3 m) in diameter by 1 ft (0.3 m) in length.

3. *Eutectic salts.* These are better suited than the alloys and are applicable up to 2 ft (0.6 m) in diameter. With care, they can be slush molded, and they are easy to remove.

4. *Soluble plasters.* These have a long plastic stage and can be wiped to contour. They are easily washed out.

5. *Frangible or break-out plasters.* These are used best with large diameters. Internal support is required, and break-out is difficult and can cause damage. Chains can be imbedded to facilitate removal.

6. *Sand—PVA.* This material is an excellent choice for diameters up to 5 ft (1.5 m) and for limited quantities. It dissolves readily in hot water, but requires careful molding control. Low compressive strength is a limitation.

7. *Inflatables.* These are not suitable where it is necessary to resist torque loads. One technique for improving the torque resistance is to fill the mandrel with a material such as sand and to apply a vacuum. Another use for inflatables is to transfer the uncured winding to a closed mold and to cure with pressurization through the mandrel.

The properties of several mandrel materials are given in Table 16.8. Figure 16.6 is a schematic of the support structure for a wash-

Table 16.8. Properties of Mandrel Materials

Material	Kerr DMM[a]	Hydrocal B-11[b]	Brak-Away[c]	Paraplast 36[c]	Sand/PVA
Type	Wash-out plaster	Frangible plaster	Frangible plaster	Soluble salt	Wash-out
Compressive strength, psi (MPa)	700 (4.8)	3800 (26.2)	375 (2.6)	14,000 (96.5)	500 (3.5)
Specific gravity	1.25	1.36	0.8	2.08	
Moisture pick-up					
% at 75% RH	0.07	0.45			
% at 70% RH			86.5		
Maximum use temperature, °F (°C)	400 (204)	400+ (204+)	400+ (204+)	350 (177)	350 (177)
Set time, minutes	20–25	45–55	10–15		
Set expansion, in./in.	0.043	0.0004	0.0015		

[a]Kerr Mfg Co
[b]US Gypsum
[c]Rezolin, Inc

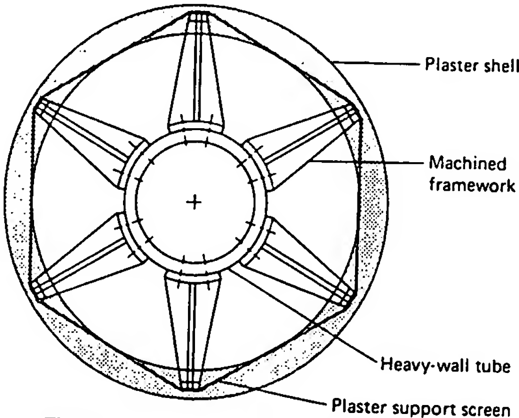


Figure 16.6. Framework for plaster mandrel.[11]

out plaster mandrel. Figure 16.7 plots mandrel thickness versus diameter for three materials. In this latter case, the vessel is designed for a pre-stress equal to 20% of operating pressure.

16.3.4. End Closures

End closures for pressure vessels are either mechanically fastened to the cylindrical portion or are integrally wound. The former method has been found practical in some commercial applications. For high performance vessels, typified by rocket motor cases, integral heads are essential. Head contours deviate from a spherical shape, which is less efficient. The fiber path yields a balance of meridional and circumferential forces and is consistent with winding conditions so that no slippage occurs. The head contours and related polar bosses are critical in vessel design. Below, the contours associated with helical and polar winding are briefly summarized.[12,16]

16.3.4.1. Geodesic Isotensoid

This contour is normally adapted to helical winding. The fiber path is taken as tangential to the polar boss (Fig. 16.8). Each point on the path is defined by its meridional and circumferential radii, r_1 and r_2, respectively. These radii are related to the X, Y coordinates, which establish the contour, in the following manner.

$$r_1 = \frac{-[1 + (Y')^2]^{3/2}}{Y''} \qquad 16\text{-}1$$

$$r_2 = \frac{-X[1 + (Y')^2]^{1/2}}{Y'} \qquad 16\text{-}2$$

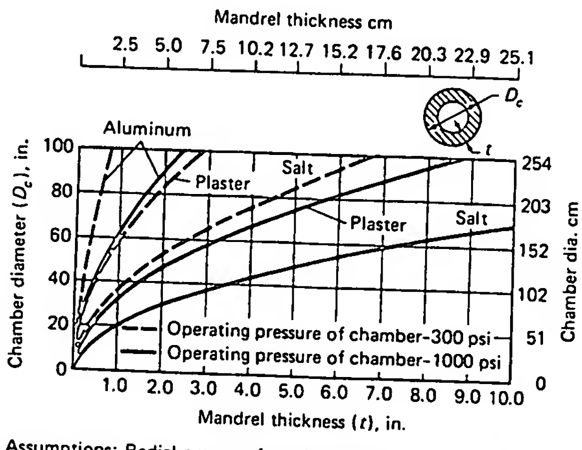
where Y' and Y'' are the first and second derivatives of Y with respect to X.

The principal membrane forces due to an internal pressure, P, are:

$$\text{Meridional: } N_\phi = \frac{Pr_2}{2} \qquad 16\text{-}3$$

$$\text{Circumferential: } N_\theta = \frac{Pr_2}{2}[2 - r_2/r_1] \qquad 16\text{-}4$$

For a balanced stress condition, the fila-



Assumptions: Radial pressure from filament winding – 20% of operating pressure of chamber. Allowable radial deflection of mandrel under winding tension – 0.020 in.

Figure 16.7. Mandrel thickness versus cylinder diameter.[12]

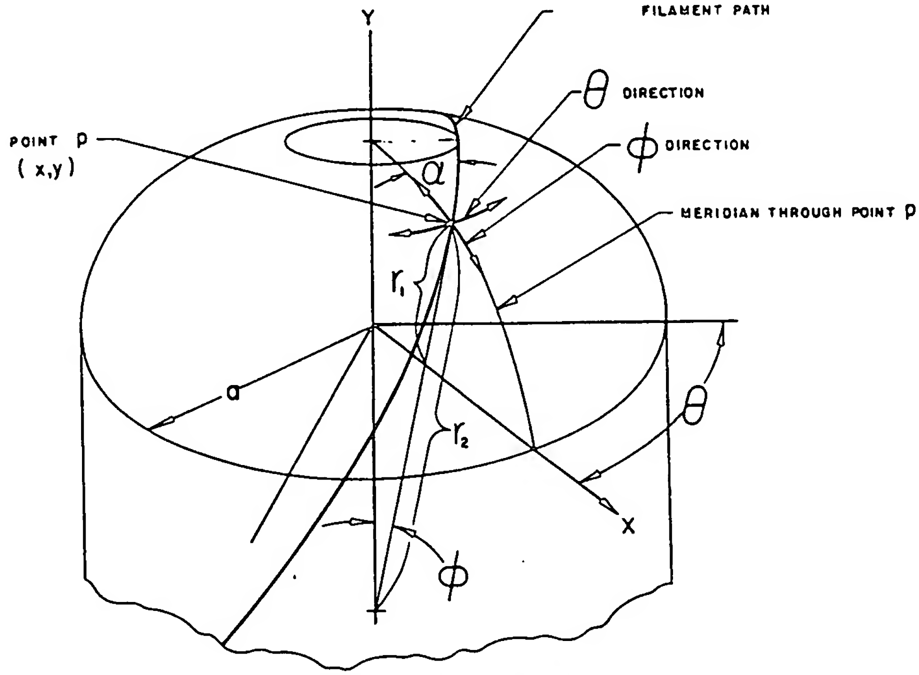


Figure 16.8. Geometry for geodesic path.[15]

ment strengths in the principal directions are equated to these forces, and the following equation results.

$$\frac{r_2}{r_1} = \frac{XY''}{Y'[1(Y')^2]} = 2 - \tan^2 \alpha \qquad 16\text{-}5$$

where α = the winding angle. For the path to be geodesic, Eq. 16-6 holds true:

$$X \sin \alpha = \text{constant} \qquad 16\text{-}6$$

At the tangency point, $\alpha = 90°$ and:

$$\text{Sin } \alpha = X_0 / X \qquad 16\text{-}7$$

where X_0 is the boss diameter.

Solution of Eqs. 16-5 and 16-7 yield the coordinates of the contour. The solution is generally obtained by a computerized step integration. Graphical solutions are also possible.[14,16] When $\tan^2 \alpha$ equals 2, Eq. 16-5 is no longer usable. The simplest solution beyond this inflection point is to continue a spherical radius to a junction with the polar boss.

16.3.4.2. Planar or Balanced in Plane

The fiber path for this contour is described as the intersection of a plane with the end closure (Fig. 16.9). Here, the principal stresses are balanced by adjusting the instantaneous radii of curvature at each point. The equation of the wrap plane is:

$$X \cos \theta = B + AY \qquad 16\text{-}8$$

The filament angle at any point is given by Eq. 16-9.

$$\text{Tan } \alpha = \frac{A \sin \phi + \cos \phi \cos \theta}{\sin \theta} \qquad 16\text{-}9$$

$$\text{Where: } \tan \phi = -Y' \qquad 16\text{-}10$$

Equation 16-5, in conjunction with Eqs. 16-8, 16-9, and 16-10 establish the contour and the filament path.

Table 16.9 lists the coordinates for a geodesic-isotensoid contour as determined by a graphical solution. Figure 16.10 is the contour for a typical planar wrap. The calculations for both types of contours, it should be noted, are based on a netting analysis, and all the assumptions of this method are implied.

16.3.5. Material Handling and Process Controls

The equipment for transporting the strands from the roving package to the mandrel forms